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The local complex of O and B stars. I. Distribution of stars and interstellar dust*

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The O-B5 stars, supergiants, young clusters, and associations within 1 kpc of the Sun populate two flat systems inclined to each other by 19°–22°. The present paper discusses the historical background, statistical significance, composition, spatial arrangement of the contents, and interstellar extinction in the two belts. A more or less random distribution in space and in age characterizes the O-B5 stars of the "galactic belt," which is aligned nearly along the Milky Way. The "Gould belt" is inclined to the Milky Way (north in Sco-Oph and south in Orion), and exhibits a projected distribution of O-B5 stars in its mean plane that resembles a "dragonfly," with five major features defining it. A crude "diameter" of the system is 750–1000 pc, and the Sun's position is eccentric, lying toward Ophiuchus. The nuclear age of the system, while not unique, may be characterized as 3×10^7 yr from the spectral type of the broad main-sequence turnup near B2.5. Most of the O-B2 stars and youngest stellar groups near the Sun belong the Gould belt, but both belts have approximately equal space densities of B3-B5 stars and similar average values of interstellar extinction. Although the Gould belt is about three times as compressed vertically as is the galactic belt, each belt shows the same increasing concentration to a plane for the following objects: stars, interstellar dust, and centers of star groups. A small "hole" around the Sun occurs in the distribution of dust and O-B5 stars.

INTRODUCTION

THE O and B stars near the Sun define roughly two great circles on the sky. The *galactic belt* of stars is aligned nearly along the Milky Way, while the *Gould belt* is inclined to it by about 20°. This second belt dips to its most southern latitudes in Orion and rises in the north to Sco-Oph. Although its existence is unquestioned, its spatial nature and relation to the stars of the galactic belt are still poorly understood.

In a series of papers on the O and B stars within 1 kpc of the Sun, we intend to investigate the spatial and kinematical properties of the two stellar belts. The present paper deals successively with the historical investigations, spatial orientation and extent, stellar composition, and gross extinction properties of the Gould belt as compared with the galactic belt. Although kinematical data are ignored in this paper, a fair picture nevertheless emerges, which sets the stage for our future kinematical studies. The present study is based primarily on a catalog of O-B5 stars, compiled with modern photometry (U, B, V, or equivalent) and MK or HD spectral classifications. All data used predate the middle of 1966, and although it might have been desirable to update the catalog with more recent data (particularly MK spectral types for southern stars), we have found that coverage of the whole sky by the present catalog is fairly complete down to $V=6$, but that coverage ends at about $V=9$. Improvement is actually needed most for the highly obscured northern stars from Scorpius to Cygnus. The catalog is described in the Appendix, in addition to supplementary (and more nearly complete) catalogs of luminous supergiants, young clusters, and associations, within about 1 kpc of the Sun.

I. HISTORICAL SURVEY

No connected account appears to exist relating the history of investigations of the Gould belt. The short, but documented, account given here omits exclusively kinematical studies, which will be discussed in a future paper.

A. Naked-eye Stars

Vague recognition of a "local system" containing the Sun and the brighter stars appeared in early speculative models of the Milky Way when the latter was treated as being a composite of scattered star systems (Lambert 1760; Michell 1767). However, the early (as well as the much later!) homogeneous models of the Milky Way, like the disk model of Kant or the preliminary "cloven grindstone" model of W. Herschel with its projecting "strata" of stars, tended to subordinate irregularities in the distribution of stars. Thus, W. Herschel, though he later adopted ideas like those of Lambert, never connected the Scorpius stratum with the Orion stratum in the opposite part of the sky. Some time after 1833, while at the Cape of Good Hope, J. Herschel (1847) effected the proper connection by noting that a stratum of bright southern stars appears as a belt inclined by about 20° to the galactic equator. Independently, while commenting on the arrangement of stars in the Milky Way, W. Struve (1847) suggested that the densest layer of stars may lie in two planes,

* Contribution marking the centennial of B. A. Gould's (1874) announcement of the discovery of his eponymous belt of stars.

inclined to each other by about 10°, even though he preferred a "broken plane" model.

Alexander (1852) proposed that the Milky Way was a four-armed spiral nebula, in which the Sun and bright stars belonged to a central spheroidal cluster, and Herschel's belt of southern stars formed an "outshooting" of a spiral arm. He was frankly inspired by Lord Rosse's discovery in 1845 of the spiral nature of some nebulae and by the Herschels' allusions to possible "crooked" or "curved" branches of the Milky Way. A side interest in Herschel's belt was also shown by Proctor (1867, 1868), who traced its path around the whole sky. Although Secchi (1879) confirmed this path, he seems not to have attempted to differentiate stars inside and outside the belt by applying his new method of spectral classification.

The most detailed corroboration of Herschel's discovery was made independently by Gould (1879). Finding the belt of bright stars to be nearly a great circle (1874), he then determined its pole, nodes, and an inclination of 17° to the galactic equator. His conclusion was that "Gould's belt," as it came later to be known, was a small cluster of less than 500 stars, partly bifid, flattened, and distinct from the vast Milky Way organization, which apparently contained two or more superposed "galaxies." Celoria (1877) on the other hand, suggested that the bright (near) stars and the faint (distant) stars form two separate rings around the Sun, inclined to each other by 19° or 20°. The Milky Way alone had already been described as a ring by Kepler, Wright, J. Herschel, and others before 1850; as a ring surrounding an inner ring of nearby clusters and stars by May in 1853; and, in 1869, as a broken "spiral" ring by Proctor, who was influenced primarily by the Herschels' remarks about spiral-like groups of stars. Sutton (1891) noted the irregular distribution of stars on the sky where the Gould belt crossed the galactic belt, and suggested that, although the two belts were broken in Ophiuchus and Carina respectively, they were nevertheless rings, having equal radius and intersecting each other. He considered the Gould belt to be the more fundamental of the two star systems. Easton (1900), by combining several of his predecessors' ideas in 1898, conceived of a vast galactic spiral system centered in Cygnus, with its spiral arms situated principally in two planes inclined to each other by about 20° and with the Gould belt appearing as the outer part of one spiral arm. Later (1913) he regarded the Gould belt as formed rather of interarm branches. However, Espin (1913) was able to explain the basic observed phenomena simply by two coplanar, intersecting rings.

In the meantime, the existence of the Gould belt had been confirmed again and again by star counts made from various catalogs compiled during the second half of the nineteenth century. Ristenpart (1892) and Prey (1896) solved for two best-fitting planes, with a resulting angle of inclination between the planes of 21°–37° and 16°, respectively. Stratonoff (1900, 1901) confirmed Schiaparelli's (1889) inclination of about 20°, and suggested that the Gould belt might be a small cluster embedded in a larger group of clusters. A noticeable inclination (but of undetermined amount) was also found by Burns (1902) and Downing (1902). In more detailed work, Newcomb (1901, 1904) obtained an inclination of 5°–10°, and questioned whether the Gould belt might be only a chance configuration of stars. Subsequent studies tended to favor the more frequently derived inclination of 10°–20° (Kobold 1906; van de Linde 1921; van Rhijn 1929). The relation of the Gould belt to the ellipsoidal "Kapteyn universe" (perfected between 1892 and 1922) was therefore ambiguous and was usually ignored.

Two further naked-eye observations are of some interest here, namely, Easton's (1900, 1903) and, independently, Barnard's (1927) descriptions of the distribution of diffuse galactic light, which also lies continuously along the Gould belt. Finally, it is worth noting that the well-known branch running from Ara to Cygnus (through Sco-Oph) was originally described by Ptolemy (ca. 150).

B. Early-type Stars

It was noticed early that the B stars are congregated mostly along the Milky Way (Pickering 1891). Boraston (1893), Stratonoff (1900), and Easton (1913) later identified the brighter B stars as members of the Gould belt. While not recognizing this fact, Boss (1910) and Hertzsprung (1912) found that the system of B stars was inclined somewhat to the galactic equator. The system also exhibited a maximum space density in the direction of Carina at roughly 100 pc from the Sun (Walkey 1914). These features were confirmed independently by Charlier (1916). Then Shapley (1919a) reidentified the system of B stars as a "local cloud," connected it with Gould's belt, and, elaborating on a remark of Gould's (although J. Herschel in 1849 had made a similar remark), pointed out that the maximum space density of stars shifted progressively toward Sagittarius as stars of fainter magnitude were considered (see also Shapley and Cannon 1922b). Most of the O stars (Pickering 1891) and *c* stars (Hertzsprung 1912) are now known to be quite distant, and therefore, did not show the Gould belt phenomenon. Contradictory results for the Be stars were obtained by Curtiss (1926) and by Gerasimovič (1927), but Curtiss's finding of some concentration to the Gould belt was independently confirmed by Merrill and Burwell (1933). The brighter A stars (Boraston 1893; Shapley 1919a: Shapley and Cannon 1922a) also showed some concentration to the Gould belt, but stars later than A did not. Eventually, spectroscopic binaries of spectral type B and A (Karpowicz and Zonn 1955), β Cephei variables (Lesh and Aizenman 1973), and faint variables associated with nebulosity, such as the T Tauri stars (Wenzel 1961; van den Bergh 1966), were also located in the Gould belt.

Gerasimovič (1926) studied the space distribution of a larger number of B stars than had Charlier (1916), but he did not find so clearly inclined a system as Charlier had found and had later confirmed (Charlier 1926). Evidently, the effect Shapley and others had noted earlier about fainter stars being more concentrated to the galactic belt was affecting Gerasimovič's results. The star counts of Seares (1928) confirmed Shapley's (1919a) work on B stars, and led Seares to speculate that the Gould belt is an enormous "knot" of 6000 pc diameter, in an arm of a larger galatic spiral system. (It may be recalled that during 1925–1927, Lindblad and Oort had discovered the rotation of the galactic system around Shapley's distant center in Sagittarius.) Further evidence of a local system among the B stars was found by Shajn (1928), Seares (1931), and Stroobant (1934), although the two independent investigations showed dimensions of the system much smaller than Seares's estimate. In a radical reassessment of the situation, Shapley (1930) suggested that the local system might be a small discoidal galaxy within a dense cluster of galaxies, but this idea never took root. An excellent resume of the results derived from general star counts during the 1930's has been given by Bok (1937). Although corrections for interstellar extinction were introduced, it was not clear even by 1937 that the Sun actually inhabited a giant spiral system nor what the relationship of the Gould belt to the greater galactic system was. Bok suggested that the local system was possibly a spiral arm running from Cygnus to Carina.

Further studies based on general star counts (e.g., McCuskey 1939) did not clarify the vexing situation, although Oort in 1938 was able to demonstrate, provisionally, the existence of two large "spiral arms" on either side of the Sun. Miczaika's (1947) and Chabibullin's (1949) general star counts led to a further denial of any local system. In a detailed kinematical study, Schmidt (1949) combined star counts with space motions for the B stars (without, however, differentiating stars in the Gould belt from those in the galactic belt) and found, as was by now familiar, a local system similar to Charlier's, but with one difference: he concluded that the local B stars form a small two-armed spiral system embedded in the outskirts of the larger galactic system.

Soon thereafter, two parallel studies of luminous O, B, and A stars established that the Gould belt is neither a local spiral system nor a spiral arm in the greater galactic system (Nassau and Morgan 1951), and revealed conclusively for the first time the spiral structure existing in the greater galactic system (Morgan, Sharpless, and Osterbrock 1952). (Radio observations of the Milky Way by Bolton and Westfold in 1950 had already suggested some galactic spiral structure, which was confirmed definitively by Oort, van de Hulst, and Muller in 1952). Concerning the Gould belt, Schnirelman (1952), from a study of the local B stars, arrived at the same conclusions as had Nassau and Morgan. Further work on the structure of the Gould belt determined its major dimension to be either near Shapley's early value of ~1000 pc (Schnirelman 1952; Blaauw 1956; Eggen 1961; Klare and Neckel 1967; Lesh 1968) or near Schmidt's more recent value of ~600 pc (Nassau and Morgan 1951; Sekanina 1959; Bonneau 1964; Dewhirst 1966; Clube 1967; Froeschlé 1969). The center of the local system was placed between Orion and Carina, within 150 pc of the Sun. Gum (1955) and Dewhirst (1966) characterized the system, respectively, as a "fin" or a "twist" of the local spiral arm. Similar systems, described as "shingles" by Schmidt-Kaler and Schlosser (1973), have been discovered in the neighboring inner arm.

C. Clusters and Associations

Vast stellar clumpings like those in Orion and Scorpius were recognized by W. Herschel, but their spatial and kinematic identities were first clearly demonstrated by Kapteyn (1914, 1918) in the case of the Sco-Cen, Vela, and Orion groups. Pannekoek (1924, 1929) derived the positions and volumes of space occupied by these and other groups. His catalog of stellar groups bears a startling resemblance to modern lists of stellar associations (rediscovered by Ambartsumian in 1949), if allowance is made for Pannekoek's neglect of interstellar extinction. His groups certainly show the two-belt phenomenon, although Pannekoek himself disbelieved in a "local system," since stellar groups existed at all distances from the Sun. Although Charlier (1916) paid scant attention to irregularities in the B-star distribution, he did isolate the Orion and Sco-Cen groups in his later work (Charlier 1926). Among smaller aggregates, what would now be called young open clusters also showed some concentration to two belts (Melotte 1915; Doig 1926; Collinder 1931). The Pleiades cluster, for example, seemed to lie in the Gould belt (Ranyard 1891).

Many years elapsed before Blaauw's (1956) major reinvestigation of the stellar groups belonging to the Gould belt; he found the Cas-Tau moving group (Rasmuson 1921) to be a probable additional member. Eggen (1961) disputed the existence of the various isolated aggregates, and instead argued for a vast "local association," containing also the Pleiades group. His ideas were largely foreshadowed by the speculations of McAulay (1920). Blaauw (1964), however, maintained the distinction of separate groups within the Gould belt, as did Clube (1967) and Lesh (1968). Statistically, it is possible that all the unattached O and B stars have originated in now-dispersed stellar associations (Roberts 1957), without having to postulate the Gould belt as a single superassociation. Wenzel (1961) has shown that some of the T associations also belong to the Gould belt, and van den Bergh (1968) has obtained an equivalent result for the R associations.

D. Interstellar Matter

The nebulosity in Orion was first associated with the tilted zone of bright stars by J. Herschel (1849) himself, but later, many other bright emission and reflection nebulae near the Sun were found to show the same phenomenon (Proctor 1868; Easton 1900; Hubble 1922; Cederblad 1946; Gum 1955; Johnson 1956; Sharpless 1965; van den Bergh 1966). Among the dark nebulae, Barnard's "dark markings" (Shapley 1919b) and numerous other extended nebulae (Hubble 1922; Lundmark and Melotte 1926; Khavtassi 1955; Lynds 1962) also showed the phenomenon distinctively, whereas Bok's globules did so only weakly (Lynds 1962). Diffuse obscuring material lying along the Gould belt was for a long time known from the large color excesses of some of the belt's stars, particularly in Ophiuchus and Taurus, and the idea of a great flattened cloud encompassing the two regions and the Sun was suggested (e.g., Müller 1931; Becker 1935; Schmidt 1950). Although Thorndike (1934) and Vashakidze (1940) found no particular concentration of reddening material to the Gould belt, the later use of a larger number of stars confirmed the splitting into two belts (Toronzhadze and Kochlashvili 1956; Sekanina 1959; Strömgren 1962; Sharov 1963; FitzGerald 1968; Arshinova and Radzievskii 1971). The interstellar Ca II distribution also revealed the presence of the Gould belt (Struve 1927, 1928). A "zone of avoidance" for faint galaxies was first noticed to occur along the Gould belt by Proctor (1868); Hubble's (1934) work also shows "flares" extending from the galactic belt into Sco-Oph and Orion. These zones of avoidance are due to obscuration by dust in the two belts.

More recently, Lilley (1955) and others have demonstrated the close interrelationship between dust and gas near the Sun. A number of 21-cm surveys of neutral hydrogen have shown strong apparent concentrations of gas in the Gould belt (Christiansen and Hindman 1952; Heeschen and Lilley 1954; Erickson, Helfer, and Tatel 1959; Davies 1960; McGee, Murray, and Milton 1963; Lindblad 1967; Henderson 1967; Habing 1968; Goldstein and MacDonald 1969; Harten 1971; Hughes and Routledge 1972; Lindblad, Grape, Sandqvist, and Schober 1973). Although Hansen (1968) has cautioned against any simple interpretation of the high-latitude gas, P. Lindblad believes that the local gas forms an elliptical expanding ring, roughly coincident with the outer stars of the Gould belt. On the other hand, McGee and Milton (1964) have found only a lumpy distribution of local gas.

Bingham and Shakeshaft (1967) were unable to detect any evidence of the Gould belt in radio and optical polarization measurements. However, Clube (1968) suggested that the very weak magnetic field in the Gould belt may have manifested itself indirectly in the apparent distortion of the magnetic field lines of the interarm medium through which the local system is moving.

Other sources of emission and absorption in the Gould belt are various interstellar atoms, molecules, and grains—among them, $100\,\mu$ emitters, which are mostly connected with H II regions (Hoffman, Frederick, and Emery 1971).

II. COORDINATE SYSTEMS

The fundamental reference plane for our study will be taken to be the IAU galactic plane (Blaauw *et al.* 1960), to which new galactic coordinates (l, b) are referred. We shall primarily use two heliocentric coordinate systems: (1) a spherical coordinate system (r, l, b) and (2) a corresponding rectangular coordinate system (x, y, z) in which the positive x-axis and the positive y-axis point, respectively, in the directions of the galactic center ($l=0°$, $b=0°$) and of the local galactic rotation ($l=90°$, $b=0°$) and the positive z-axis points in the direction of the North Galactic Pole ($b=90°$). Further, we define a projected distance $\rho=r\cos b$.

A third heliocentric coordinate system is useful in relating stars to planes inclined to the IAU galactic plane and passing through the Sun. First, we rotate the (x, y)-plane counterclockwise about the positive z-axis through an angle ϕ. Then we rotate the plane containing the z-axis and the displaced x-axis clockwise about the displaced positive y-axis through an angle θ. The resulting transformation equation for the rectangular coordinates is

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \cos\theta\cos\phi & \cos\theta\sin\phi & \sin\theta \\ -\sin\phi & \cos\phi & 0 \\ -\sin\theta\cos\phi & -\sin\theta\sin\phi & \cos\theta \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}. \quad (1)$$

In analogy with the unprimed coordinate system, we may define a set of spherical coordinates (r, l', b').

III. SPATIAL REALITY OF THE GOULD BELT

The spatial distribution of O-B5 stars from our catalog is shown in Figs. 1 and 2. With due regard for the greater incompleteness of the data at larger distances from the Sun, it is evident from Fig. 2 that two fairly distinct, highly-flattened systems of stars appear. In the projection of stars on the (x, y)-plane, this differentiated distribution has been shown previously by Pannekoek (1924), Blaauw (1956), Eggen (1961), Bonneau (1964), and Klare and Neckel (1967); while,

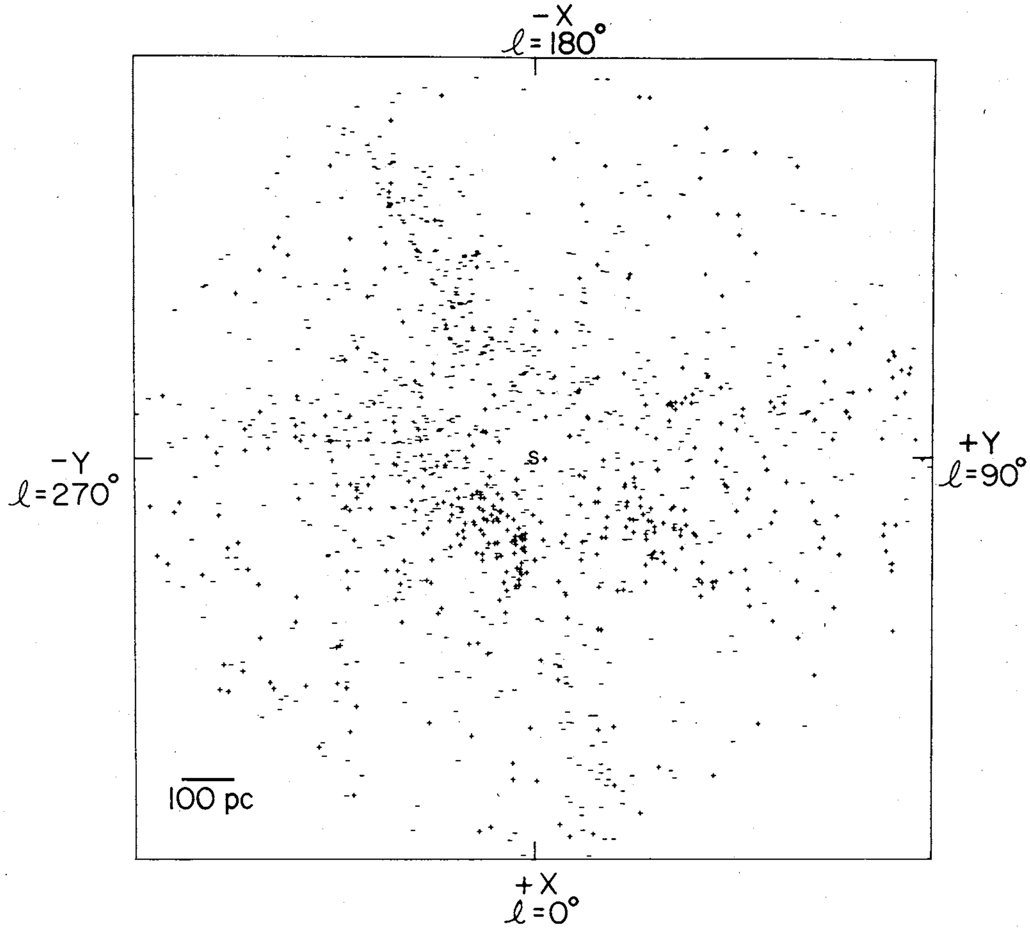

FIG. 1. Projected positions of all the cataloged O-B5 stars within $\rho = 800$ pc on the IAU galactic plane. Pluses and minuses refer to stars above and below the plane, respectively. The Sun is marked by an S.

in the projection on the (x, z)-plane, it has been shown by Charlier (1916), Shapley (1919a), Schnirelman (1952), Eggen (1961), Bonneau (1964), Clube (1967), Lesh (1968), Lesh and Aizenman (1973), and Schmidt-Kaler and Schlosser (1973). However, the stars used in our work are either more numerous and extend to a greater distance, or else have more accurately known extinction corrections than the stars used in previous investigations.

TABLE I. Least-squares solutions for mean planes through the Gould and galactic belts by using all the O-B5 stars in successive cylindrical shells around the Sun.

Belt	ρ(pc)	$l_{\rm pole}$	$b_{\rm pole}$	$h_\odot$(pc)	i	N
Gould	0–200	185°±5°	+70°±2°	12±3	68°	179
	200–400	204 ±2	+70 ±1	0±3	26	246
	400–600	206 ±3	+75 ±1	18±5	20	161
	600–800	206 ±2	+73 ±1	−11±7	21	96
Galactic	0–200	47 ±7	+37 ±3	67+14	68	44
	200–400	58 ±10	+83 ±1	37±4	26	188
	400–600	74 ±9	+83 ±1	25±7	20	138
	600–800	49 ±11	+86 ±1	0±7	21	144

The reality of the Gould belt as a spatial entity may be demonstrated statistically. Consider the relative numbers of stars above and below the galactic plane in a box of unit cross-section and of infinite extent in the direction perpendicular to the galactic plane. We wish to test at the 5% level the hypothesis that $n/N = \frac{1}{2}$, where n is the number of stars above the galactic plane and N is the total number of stars above and below the plane. The probability that the counted number of stars above the plane is n is given by the binomial law. In the present application, we have partitioned the galactic plane into a réseau of 256 squares, each measuring 100 pc on a side. Counts of O-B5 stars have been made in the boxes erected on the squares. Since no deviation from a symmetric galactic distribution is significant for $N < 5$ at the 5% level, some boxes do not contribute any useful information. In Fig. 3, the réseau contains results for those boxes with five or more stars; pluses and minuses indicate significant concentrations of stars above and below the galactic plane, respectively. From this figure, we conclude that the Gould belt is a real spatial entity.

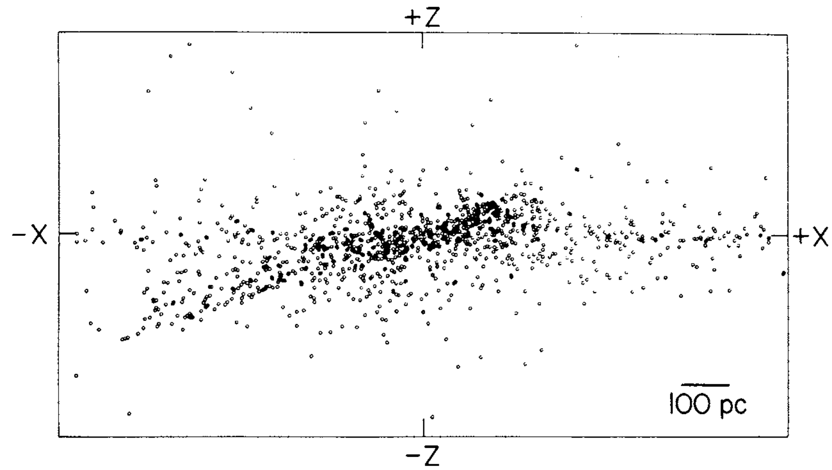

FIG. 2. Projected positions of all the cataloged O-B5 stars within $\rho=800$ pc on a plane perpendicular to the IAU galactic plane. The Sun lies at the intersection of the x and z axes.

IV. THE BEST-FITTING PLANES

An unbiased method of determining the spatial orientation and stellar membership of the two star systems is a least-squares solution for the two best-fitting planes through the local complex of stars. We adopt the following notation to describe each plane: l_{pole}, longitude of the North Pole of the plane; b_{pole}, latitude of the North Pole of the plane; and $h_\odot$, Sun's z-distance above the plane. The perpendicular height of a star above or below the plane, ζ, and the angle of inclination between the two planes, i, are other useful quantities.

Our procedure for obtaining the two planes starts with preliminary guesses for the six coefficients (in rectangular coordinates) that define the planes. Then an individual star is assigned to the particular system which is nearer in the z-coordinate. Following the assignment of all the stars, two new planes are separately solved for by determining the regression of z on x and y in the basic equation of a plane by the method of least squares. These planes are then used for new assignments, and another pair of solutions by least squares is obtained. The process is continued until the changes in the six coefficients of the planes become negligible. In practice, we always found convergence and final values that were virtually independent of the initial guesses, provided that the latter were reasonable and N was large. Thus, the final assignment of stars is unique (or nearly so), although our method of assignment produces artificially sharp surfaces on the systems on the sides that face each other, and is unreliable near the zone of intersection of the two systems.

Two groups of solutions for the best-fitting planes have been obtained. In these solutions, each object has been given unit weight. The first group is based on all the O-B5 stars in successive cylindrical shells centered at the Sun and oriented perpendicular to the galactic plane. These solutions are given in Table I. (Unless stated otherwise, standard errors are quoted in this paper.) Special conditions close to the Sun, like the local "hole" in the stellar distribution and the merging of the two star systems, noticeably influence the solutions for $\rho=0$–200 pc, but have little effect beyond. The galactic belt of stars shows a small deviation from the IAU plane for $\rho=200$–600 pc (possibly due to our method of assignment of stars to the two belts), a lesser deviation at $\rho=800$ pc (found also by van Tulder 1942), and essentially no deviation beyond $\rho=2000$ pc (see Blaauw 1960). Inspection of data for H II regions (Cederblad 1946; Sharpless 1959) reveals the same trend, as expected. It should be mentioned here that the IAU plane is defined primarily by the distribution of neutral hydrogen well inside the Sun's galactocentric radius (Blaauw *et al.* 1960). The relative proportion of O-B5 stars in the two belts is weighted heavily toward the Gould belt for $\rho=0$–200 pc, but,

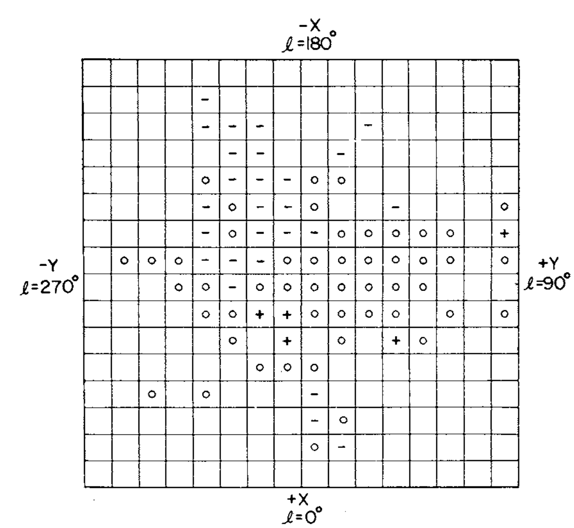

FIG. 3. Réseau centered at the Sun in the IAU galactic plane; each square measures 100 pc on a side. Stellar concentrations above or below the plane that are significant at the 5% level are indicated by pluses and minuses, respectively; otherwise, by zeroes. Squares with fewer than five stars are left blank.

TABLE II. Least-squares solutions for mean planes through the Gould and galactic belts by using various young objects within $\rho=800$ pc.

Belt	Object	Sp	Lum	$l_{\rm pole}$	$b_{\rm pole}$	$h_{\odot}$(pc)	i	N
Gould	Stars[a]	O–B5	all	209°±1°	+71°±0.4°	0±2	19°	569
	Stars	O–B5	all	205 ±1	+72 ±0.4	0±2	22	620
	Stars	O–B5	I–V	203 ±1	+71 ±0.4	−7±2	22	404
	Stars	O	all	197 ±3	+70 ±1	−12±8	17	8
	Stars	B0–B2.5	all	207 ±2	+71 ±1	−1±3	22	199
	Stars	B3–B5	all	205 ±2	+74 ±1	2±3	21	433
	Be stars	B0–B5	all	202 ±5	+74 ±2	0±10	29	59
	Supergiants	O–M	bright	208 ±8	+80 ±2	19±9	21	16
	Cl. & ass'ns	O–B5	···	201 ±6	+75 ±2	−9±11	22	12
Galactic	Stars	O–B5	all	59 ±7	+85 ±1	24±3	22	576
	Stars	O–B5	I–V	71 ±10	+86 ±1	54±4	22	305
	Stars	O	all	161 ±59	+86 ±7	40±42	17	8
	Stars	B0–B2.5	all	60 ±11	+86 ±1	32±5	22	162
	Stars	B3–B5	all	57 ±7	+84 ±1	17±4	21	386
	Be stars	B0–B5	all	43 ±10	+77 ±2	46±15	29	46
	Supergiants	O–M	bright	355 ±6	+79 ±1	−54±8	21	8
	Cl. & ass'ns	O–B5	···	285 ±7	+75 ±3	29±13	22	7

[a] Secondary plane was specified to be the IAU galactic plane.

for $\rho>600$ pc (beyond Ori OB1), the galactic belt dominates.

The second group of solutions refers to selected objects within $\rho=800$ pc. These solutions are listed in Table II, and are in quite good agreement with each other and with the results of Table I and Sec. III. In particular, the inclusion of stars without known luminosity classes, which involve about 40% of the total number of stars, does not significantly change the final result, nor does the stipulation of $z=0$ as the plane of the galactic belt stars. Definitive planes will, therefore, be selected on the basis of all the O-B5 stars in the catalog. For the Gould belt

$$l_{\rm pole}=205°\pm1°, \tag{2}$$

$$b_{\rm pole}=+72°\pm1°, \tag{3}$$

and

$$h_{\odot}=0\pm2 \text{ pc.} \tag{4}$$

This solution is remarkably close to Gould's (1879) original solution: $l_{\rm pole}=201°$, $b_{\rm pole}=+72°$, and $h_{\odot}\gtrsim0$ pc (in modern galactic coordinates). For the galactic belt

$$l_{\rm pole}=59°\pm7°, \tag{5}$$

$$b_{\rm pole}=+85°\pm1°, \tag{6}$$

and

$$h_{\odot}=24\pm3 \text{ pc.} \tag{7}$$

TABLE III. Numbers of stars within $\rho=400$ pc in the Gould and galactic belts as a function of MK spectral type and luminosity class.

Sp	Gould Belt V	IV	III	II	I	Galactic Belt V	IV	III	II	I
O	1	0	0	1	1	0	0	0	0	0
B0–B0.5	5	2	0	0	1	1	0	0	0	1
B1–B1.5	9	1	3	1	1	3	0	1	0	0
B2–B2.5	37	20	7	1	0	15	6	0	0	0
B3–B3.5	57	15	4	0	0	54	14	4	0	0
B4–B5	47	14	6	1	0	48	11	4	1	0

The Sun's elevation above the mean plane of the galactic belt B stars was found to be 20 pc by Charlier (1916), without any allowance for the presence of Gould belt stars or for interstellar extinction. Modern values for the OB stars have ranged from 10 to 23 pc (van Tulder 1942; Chernova 1948; Schnirelman 1952; Blaauw 1960), in good agreement with our value and with the value of ~22 pc derived for local H I clouds (Davies 1960).

In the following sections, we adopt the above specified planes for the two belts. Therefore, our final assignment of stars, clusters, and associations to each of the two belts will differ to some extent from the assignments enumerated in Table II.

V. COMPOSITION OF THE BELTS

The breakdown of the stellar composition of the two belts by MK type is given in Table III. With allowance for some incompleteness at spectral types B4–B5, we find that stars of the galactic belt are well distributed in age, whereas stars of the Gould belt show a noticeable main-sequence turnup around B2.5±0.5. Furthermore, about three times as many O-B2 stars per pc² lie in the Gould belt as lie in the galactic belt, while the numbers of B3–B5 stars per pc² in the two belts are about equal. The reason is simply the dominance of the very young associations Ori OB1, Sco OB2, and Per OB2 in the Gould belt. Near the Sun, only the association Lac OB1 may belong to the galactic belt. Therefore, it is not surprising that equally young objects such as β Cephei variables, luminous supergiants, and R and T associations, also tend to favor the Gould belt. However, Be stars and B-type binary systems follow simply the distribution of nonemission single B stars, as expected. Our results differ from those of Chernova (1948) and Schnirelman (1952), but otherwise agree with the data available from other sources.

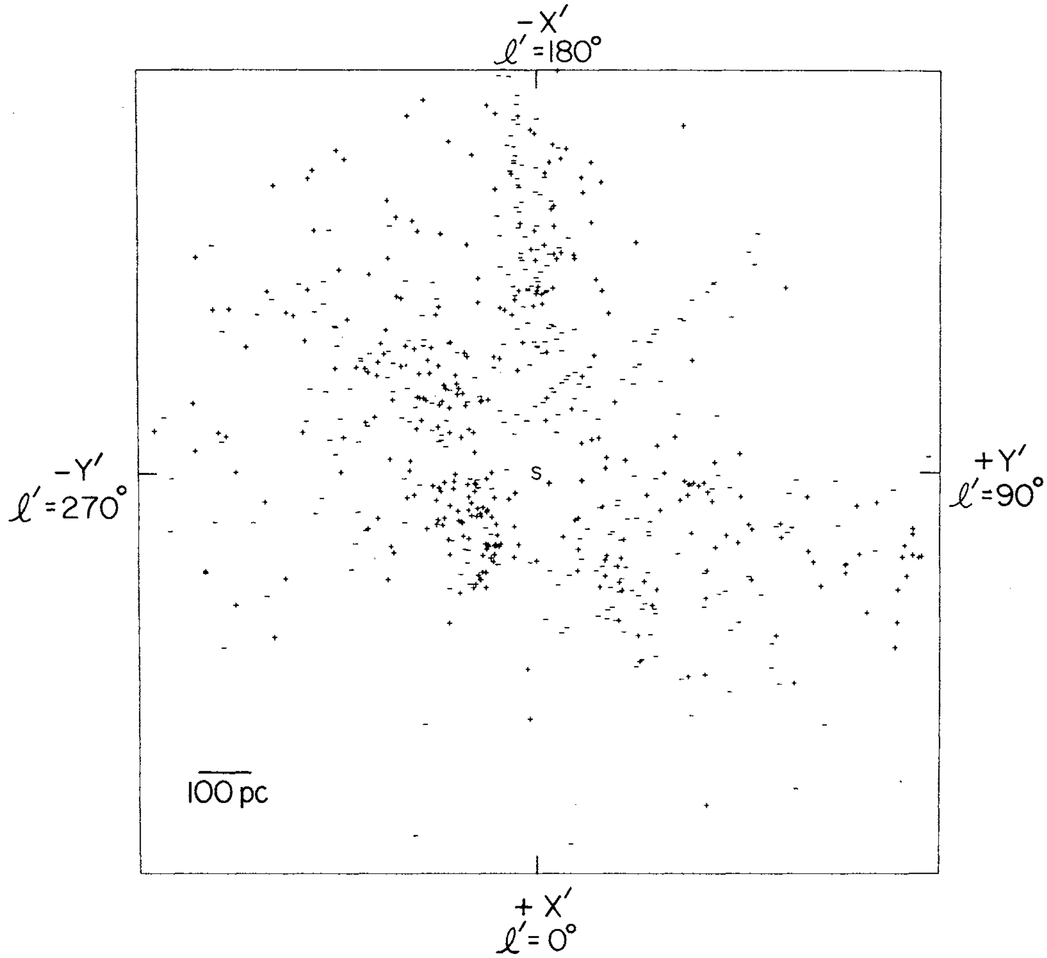

FIG. 4. Projected positions of all the cataloged O-B5 stars within $\rho=800$ pc assigned to the Gould belt, as shown on the plane of the Gould belt. The y'-axis is the line of intersection of the Gould belt and the galactic plane. Zero longitude in the primed system points toward Ophiuchus. Pluses and minuses refer to stars above and below the plane of the Gould belt, respectively. The Sun is marked by an S.

The possibility of improving the assignment of stars to the Gould belt presents itself, since one might reject all stars later than B2.5 with luminosity classes II and III. However, the number of such stars is too small to warrant performing an iteration for new planes. On the other hand, it would be dangerous to reject all O-B2.5 stars from the galactic belt, since Lac OB1, for example, is probably a member of this belt.

There appears to be no significant difference in the helium abundances of the young objects in the two belts, according to recent determinations both for the O and B stars in Sco OB2 and Ori OB1 (Leckrone 1971; Norris 1971; Watson 1971; Auer and Mihalas 1972; O'Mara and Simpson 1972) and for the Orion Nebula (Palmer *et al.* 1969; Peimbert and Costero 1969), as compared with objects in the galactic belt, including Lac OB1 (see the references above). Although the helium abundance determined for ζ Per in Per OB2 (Cayrel 1958) is rather low, it is nonetheless approximately equal to the helium abundances determined for other early-type stars at a period when the data and methods used were less refined than at present (see Traving 1966). The metals abundances also do not appear to vary significantly between the Gould belt and the galactic belt (Traving 1966; Grabowski 1969; Watson 1971).

VI. STELLAR DISTRIBUTION

A. Projected Distributions in the Planes

The O-B5 stars assigned to the Gould belt are shown projected onto the plane of the system in Fig. 4. In the primed coordinate system (based on $\phi=25°$, $\theta=18°$), the positive and negative x'-axes point toward Ophiuchus and Orion, respectively. A convenient approximate relation between the primed and unprimed longitudes is $l'\approx l-25°$ since θ is small.

Interpretation of the arrangement of the stars in Fig. 4 requires some care. Patchiness is caused both by physical clusterings and by the irregular distribution of interstellar material. Heavy obscuration can produce empty "lanes" radiating from the Sun. The sparsely populated strip along the line of intersection of the Gould belt and the galactic belt is apparently not due to interstellar obscuration, but may result from our numerical method of assigning stars to each belt. On the other hand, smoothing is introduced by our use of statistical absolute magnitudes for individual stars. In the case of stars belonging to a physical group, the latter effect shows up as a radial elongation of the group. Not all of the apparent elongation is spurious, however, because many of the groups do possess a considerable spatial extent, as is evidenced by their wide angular diameters.

The overall aspect of the Gould belt can be described as that of a "dragonfly." The main features producing this resemblance are the following:

Feature	l	r(pc)
Her-Lyr	50°–70°	150–350
Per OB2	156 –162	380–420
Ori OB1	200 –215	200–600
Pup-Vel	235 –275	200–400
Sco-Cen	290 –360	100–250.

The associations Per OB2, Ori OB1, and the Sco-Cen complex which contains Sco OB2 are well known (see, e.g., Blaauw 1964). The Her-Lyr group is less well-known, appearing explicitly only in Pannekoek's (1929) list. Its reality is in some doubt because the star motions there appear to be random (Blaauw 1956) and because numerous dark clouds obscure the quadrant $l=0°$–$90°$ ($l'=335°$–$65°$) except for a gap near $l=60°$ ($l'=35°$) (Khavtassi 1960; Lynds 1962). The δ Lyr cluster is located at high latitude in the clear area. Pannekoek (1924) investigated the Pup-Vel complex, but later listed it as five separate groups, while Upton (1971) listed three groups and Straka (1973) one, although these various groups seem to be farther away than ours. The dispersed group of stars at $r\sim700$ pc toward $l=105°$ ($l'=90°$) is part of Cep OB2 and Cep OB3; these distant associations are probably members of the galactic belt, and, therefore, their appearance in the Gould belt is only the formal result of our method of assigning stars. The quadrant $l=110°$–$200°$ ($l'=85°$–$175°$) is sparsely populated, as Weaver (1953) also noted, except for the Per OB2 association and the extended Cas-Tau group, which spreads over $r=0$–400 pc (Blaauw 1956) and contains the α Per cluster and, possibly, the Pleiades group (Eggen 1961). Like the Her-Lyr group, the Cas-Tau group is relatively old and is probably not a true physical aggregate (Petrie 1958; Crawford 1963). Thus, with the exception of Per OB2, the half of the Gould belt which contains these dispersed groups having very few stars earlier than spectral type B2 is "older" than the other half. (However, young stars are known to be still forming in the dark clouds throughout the Gould belt.) Interestingly, McGee and Milton (1964) have pointed out that the local hydrogen clouds, such as the Sco-Oph, Pup-Vel, and Ori-Tau-Per clouds, seem to form a larger complex; this proposed complex coincides well on the sky with our model of the Gould belt based on the *youngest* O and B stars. The expanding ring of gas postulated by P. Lindblad, if it exists, may surround the local "hole" in the gas around the Sun or possibly the periphery of the distribution of hot stars in the Gould belt.

It should be noted that some authors (Sec. I-B) draw a more circumscribed Gould belt system, often by omitting Ori OB1. However, we have found a continuous extended system when distant stars are included. The lateral dimensions of the system suggested by Fig. 4 are 800 pc in the direction of Orion, 300 pc toward Ophiuchus, and, uncertainly, ~500 pc on either side of the Sun. Since the Gould belt intersects the galactic belt along a line from Cassiopeia to Carina, its width in these directions is bound to be poorly determined. Klare and Neckel (1967, Fig. 3) have presented a coarse plot of OB stars out to $\rho=1500$ pc. Their plot shows that the tilted plane which we have called the Gould belt system does not extend any further than the distance limits that we have determined above.

Schnirelman (1952) has pointed out that any determination of the boundaries of the Gould belt by using an envelope around the most distant members will exaggerate the distance to the boundary by an amount proportional to the statistical error of the distances of the farthest stars. This error for a single star is due primarily to the uncertainty of the adopted absolute magnitude, arising from the possible error (and the cosmic dispersion) of the mean absolute magnitude assigned to the spectral type, which may itself be in error. Adopting 0.5 mag for the uncertainty of M_v, we find that the distance may be in error by about 25%. For the Gould belt, a 25% decrease in our previously derived distance to the boundary would reduce the "diameter" of the system to about 750 pc.

The O-B5 stars assigned to the galactic belt are shown projected onto the IAU galactic plane in Fig. 5. The inclination of the galactic belt is evident in this figure. The distribution of stars seems otherwise to be fairly random, except in the sparsely populated quadrant $l=110°$–$200°$, noted above, and in the Sct-Aql sector $l=20°$–$50°$, where the obscuration is particularly heavy (although significant obscuration occurs everywhere along $l=330°$–$150°$). Since our data for the later spectral types do not extend far enough, there is no evidence of the concentrations of B5 stars in the directions $l=77°$, $129°$, and $165°$–$197°$ found by McCuskey (1956). The Lac OB1 association at $l=97°$ is also not very prominent. The general uniformity of the distribution of stars in the galactic belt lends

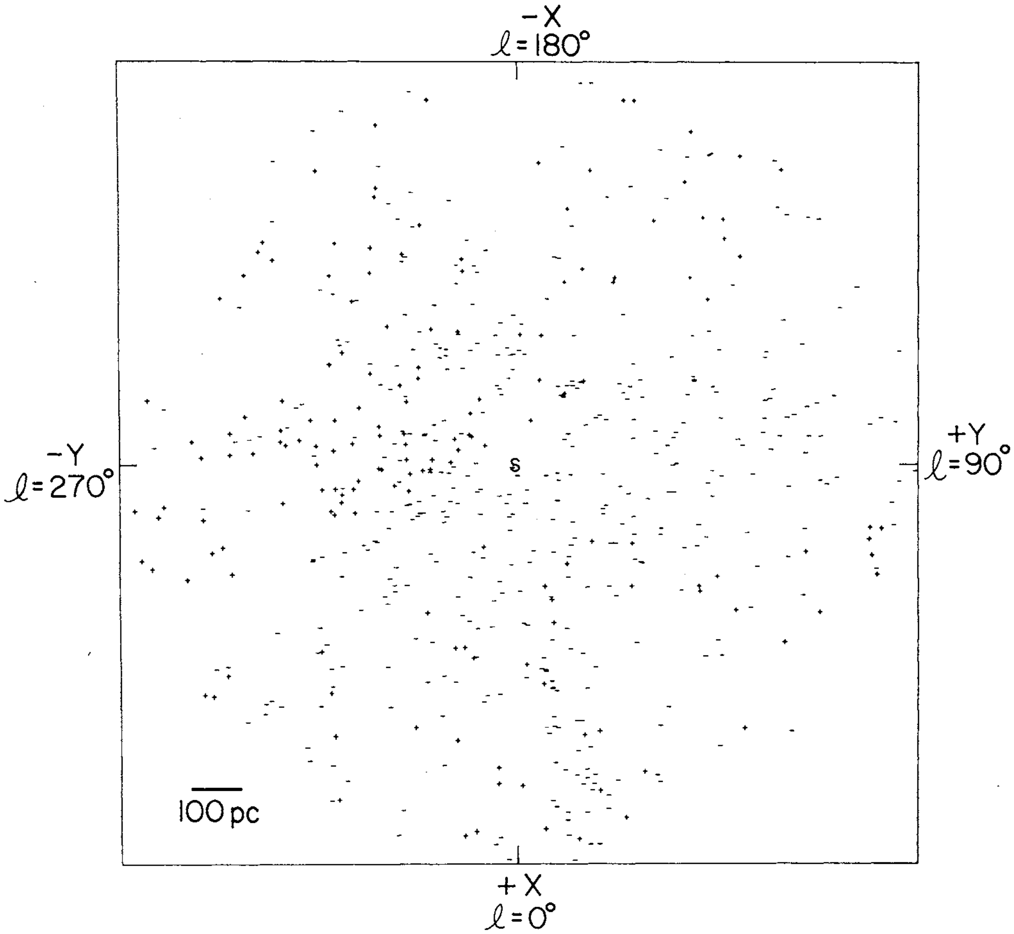

FIG. 5. Projected positions of all the cataloged O-B5 stars within $\rho = 800$ pc assigned to the galactic belt, as shown on the IAU galactic plane. Pluses and minuses refer to stars above and below the plane, respectively. The Sun is marked by an S.

support to the significance of the star clumpings found in the Gould belt.

One remarkable small feature of the distribution of O-B5 stars deserves to be pointed out. This is the "hole" immediately surrounding the Sun, evident in Figs. 1, 4, and 5 (see also Boss 1910), and appearing to a lesser extent in the distribution of B6-B9 stars (Froeschlé 1969, Fig. 7). A "hole" can also be observed in the distribution of interstellar dust determined from stellar color excesses (Becker 1939; Eggen 1963; FitzGerald 1968). Indirectly, the same feature showed up in our calculations of the average interstellar extinction as a function of distance from the Sun (Section VII), and the "hole" appears also in the distribution of interstellar hydrogen, as determined from the Lα absorption lines in early-type stellar spectra (Savage and Jenkins 1972). The projection of the "hole" on the galactic plane is roughly a circle, with a diameter of about 200 pc and with the Sun displaced from the center by about 50 pc toward $l = 0°$.

B. Location of the Centers

The center of the Gould belt has been determined by three methods. First, by inspection of Fig. 3, the roughly elliptical area encompassing the statistically most significant part of the Gould belt appears to have a geometric center at 200–300 pc from the Sun in the direction of Orion. Second, by examining Fig. 4, the broader, but more irregular, area encompassing all of the assigned Gould belt stars has a poorly defined geometric center at 200–300 pc in the direction of Canis Major. Third, by numerical computation, the centroid, or average of the star positions, is found to depend sensitively on the volume of completeness of the star counts, but is listed for several cases in Table IV. As expected, the distance of the centroid increases if intrinsically brighter stars (i.e., of earlier spectral type) are used. Just as Shapley found that the apparent center of the Galaxy shifts from Carina to Sagittarius as progressively more distant B stars are considered, so we find an analogous shift of the center of the Gould belt from Carina to Orion. This effect is confirmed by

TABLE IV. Centroids of positions of various young objects within $\rho=800$ pc which have been assigned to the Gould belt on the basis of separate two-belt solutions.

Object	Sp	Lum	l	b	r(pc)	N
Stars	O	I–V	188°±27	−18°±9	277±80	7
Stars	B0–B0.5	I–V	188 ±24	−16 ±9	185±52	20
Stars	B1–B1.5	I–V	191 ±12	−17 ±5	252±42	49
Stars	B2–B2.5	I–V	227 ±16	−17 ±7	106±27	98
Stars	B3–B3.5	I–V	237 ±11	−18 ±5	126±24	132
Stars	B4–B5	I–V	257 ±10	−3 ±4	121±23	100
Supergiants	O–M	bright	206 ±40	−17 ±12	151±84	16
Cl. & ass'ns	O–B2	···	138 ±34	−6 ±8	212±122	10

using other intrinsically bright objects—supergiants and the youngest clusters. For definiteness, we adopt here the O-B1 stars, since the centroid shifts rapidly for stars later than B1. These 62 objects then yield:

$$l=180°\pm13°, \tag{8}$$

$$b=-16°\pm\ 5°, \tag{9}$$

and

$$r=212\pm34 \text{ pc}. \tag{10}$$

Thus, the three methods give essentially the same location of the center. Correction for the statistical error of the most distant stars would reduce the distance of the center (in the first two methods) by about 50 pc, but would have a much smaller effect in the third method.

Those authors who have restricted their studies of the Gould belt to relatively nearby stars have usually found a circular system with the center at the Sun. Such a result is always suspect, and the effect shows up in our Fig. 5 for the galactic belt. Other authors have found the Sun displaced toward the hemisphere $l=0°$–$180°$ (e.g., Nassau and Morgan 1951; Eggen 1961; Dewhirst 1966; Clube 1967). However, our conclusion that the Sun is displaced toward Ophiuchus is based on an investigation of stars at rather large distances, and is in agreement with the survey of very distant stars by Klare and Neckel (1967), as well as with Gould's (1879) original study. Unfortunately, the location of the Sun with respect to the center of the neutral hydrogen distribution in the Gould belt seems to be still virtually indeterminate (compare the results of Harten 1971; Lindblad *et al.* 1973).

The formal centroid of the local galactic belt has also been determined. As expected, it is not significantly different from the solar position.

C. Distributions Perpendicular to the Planes

The characteristic heights of O-B5 stars above and below the planes of the two belts have been determined. However, two artifacts of the way in which the planes were derived will affect these heights, namely: (1) the sharp cutoff in the stellar distributions on the sides of the belts facing each other, and (2) the arbitrary assignment of stars on the far sides of the belts to the nearer belt. In this situation, the most accurate procedure seems to be to use only the stars which are located on the far sides of the belts, are fairly distant from the region of intersection of the two belts, and are close to the densely populated mean planes of the belts. Since trial calculations indicate that adoption of the last two stipulations does not significantly alter the results, we have ultimately decided to ignore only stars on the facing sides of the belts.

For purposes of later comparison, five characteristic heights are defined: the median absolute height $|\zeta|_m$; the mean absolute height, $\langle|\zeta|\rangle$; the rms height, $\langle\zeta^2\rangle^{\frac{1}{2}}$; the exponential scale height, β, in

$$n(\zeta)=n_0e^{-|\zeta|/\beta}; \tag{11}$$

and the Gaussian dispersion, σ, in

$$n(\zeta)=n_0e^{-\zeta^2/2\sigma^2}. \tag{12}$$

Here, n represents the number density of stars. The exponential distribution has the following characteristics: $|\zeta|_m=(ln2)\beta$, $\langle|\zeta|\rangle=\beta$, and $\langle\zeta^2\rangle^{\frac{1}{2}}=2^{\frac{1}{2}}\beta$. The Gaussian distribution has: $|\zeta|_m=0.674\sigma$, $\langle|\zeta|\rangle=(2/\pi)^{\frac{1}{2}}\sigma$, and $\langle\zeta^2\rangle^{\frac{1}{2}}=\sigma$.

Our empirical results for B0-B5 stars and for the young star groups are given in Table V, where β and σ have been determined by counting stars in equal intervals of $|\zeta|$ and solving for the unknowns by the method of least squares. The slightly greater vertical scatter of more distant stars is due in part to the correspondingly larger accidental errors in distance and in part to observational selection, since the lower-lying stars in each belt are more heavily obscured by interstellar matter and therefore are less likely to have been discovered. These suggestions are confirmed by the rather slowly increasing vertical scatter shown by the intrinsically brightest stars (those of spectral types B0-B1.5) within successive cylindrical shells around the Sun. Thus, the thickness of each belt is probably virtually uniform over the belt.

Although the evidence is not conclusive, the Gaussian distribution seems to characterize well the objects of the Gould belt, but less well the objects of the galactic belt. The exponential distribution provides the best fit to all the objects combined. The mean vertical scatter of galactic belt stars is found to be two to three times larger than that of Gould belt stars, but, in each belt,

TABLE V. Characteristic heights of B0–B5 stars with MK classifications and of young clusters and associations.

Belt	Object	ρ' (pc)	$\|\zeta\|_m$ (pc)	$\langle\|\zeta\|\rangle$ (pc)	$\langle\zeta^2\rangle^{\frac{1}{2}}$ (pc)	β (pc)	σ (pc)	N
Gould	Stars	0–200	19	22	29	27±4	34±4	62
	Stars	0–800	21	26	33	27±1	37±1	214
	Cl. & ass'ns	0–800	12	14	17	...	...	9
Galactic	Stars	0–200	40	62	99	55±18	45±7	35
	Stars	0–800	59	70	96	74±28	65±15	154
	Cl. & ass'ns	0–800	45	55	76	...	...	10
	Cl. & ass'ns[a]	0–800	39	40	50	...	...	9
Combined[b]	Stars	0–200	35	50	74	46±7	48±2	164
	Stars	0–800	50	70	95	70±3	61±3	688
	Cl. & ass'ns	0–800	45	63	79	68±36	61±19	19

[a] Omitting Lac OB1.
[b] Referred to the IAU galactic plane.

the centers of the star groups are significantly less dispersed vertically than are the stars themselves.

Not unexpectedly, the characteristic heights of stars in the Gould belt are much smaller than the belt's "total half-thickness" of 35–200 pc estimated, rather vaguely, by previous authors (Eggen 1961; Dewhirst 1966; Clube 1967). Our derived characteristic heights, 50–90 pc for all stars referred to the galactic plane are close to Charlier's (1916) vertical dispersion of 64 pc and to more recent values, ranging from 42 to 76 pc (van Tulder 1942; Chernova 1948; Schnirelman 1952; Kurochkin 1958; Sekanina 1959; Blaauw 1965; Klare and Neckel 1967; Borzov 1970). No convincing evidence appears in our work for an increase of characteristic height with advancing spectral type, such as was found by van Tulder (1942). In this we agree with Chernova (1948) and Schnirelman (1952).

In the Gould belt, the centers of young clusters and associations show a particularly strong concentration to the plane of the system, with $\langle\zeta^2\rangle^{\frac{1}{2}}=17$ pc. The amount of warp from a perfect plane is apparently negligible, because we find $\zeta=+13$ pc for Sco OB2 and $\zeta=-23$ for Ori OB1 and Per OB2.

In the galactic belt, the centers of young star groups are considerably more dispersed vertically, even when Lac OB1 is omitted. Becker (1963) gives a mean absolute height of 53 pc for all O-B6 clusters and associations referred to the galactic plane, and we obtain a similar value of 63 pc. Lac OB1 is a special case. Although it lies far below the mean planes of both belts, it appears to be connected to the galactic belt by a "flare" of stars (Blaauw 1956), of dust (Hubble 1934; Sharov 1963), and of neutral hydrogen (Christiansen and Hindman 1952; Davies 1960; McGee and Murray 1961). Blaauw (1956) has discovered a second "flare" near $l=80°$ at ~ 300 pc from the Sun.

VII. INTERSTELLAR EXTINCTION

The detailed distribution of obscuring material near the Sun has already been determined by many authors from star counts and stellar color excesses. It is our purpose mainly to establish the average interstellar extinction suffered by starlight traversing a unit distance, in the planes of the two belts. We employ (1) color excesses of B0-B5 stars with known MK luminosity classifications, and (2) the ratio $A_V/E_{B-V}=3.0$. Only stars on the untruncated sides of each belt will be used.

Idealizing the distribution of obscuring matter to homogeneous plane-parallel layers of dust above and below the mean plane of each belt, with an exponential fall-off of density with a scale height β, we may express the extinction in Parenago's form

$$A=\alpha|\csc b'|(1-e^{-|\zeta|/\beta}), \qquad (13)$$

where α and β are parameters to be determined. Or we may substitute for α a quantity $\gamma=\alpha/\beta$. It is clear that α is the extinction at infinity in the direction perpendicular to the plane and that γ is the rate of increase of extinction with distance in the plane.

A large number of solutions for α, β, and γ have been obtained by the method of least squares with all stars given equal weight. These solutions have been based on different formulations of the equation of condition, different distance criteria, and (unimportantly) different ranges of stellar spectral type. Unfortunately, the patchiness of the obscuring matter defeats, to some extent, our efforts to obtain a consistent average picture of the interstellar extinction. In particular, it is not at all certain that an exponential distribution characterizes the mean vertical arrangement of the dust, just as it may not characterize that of the stars (Sec. VI). Nevertheless, our results are listed in Table VI, where the mean values (and their extreme ranges) as based

TABLE VI. Mean parameters of interstellar extinction for the Gould belt, the galactic belt, and the combined (IAU) belt [Estimates of the maximum error are quoted.].

Belt	α (mag)	β (pc)	γ (mag kpc^{-1})	$\langle A/r\rangle$ (mag kpc^{-1})
Gould	0.07±0.03	25±15	2.5±1.0	1.5±0.2
Galactic	0.12±0.02	60±30	2.0±0.5	1.6±0.2
Combined	...	...	...	1.3±0.1

on the different solutions are given. The quantity $\langle A/r \rangle$ refers to the rate of increase of extinction with distance averaged over all stars.

Previous work has already established that the vertical scale height of obscuring matter near the Sun is about 40–100 pc (FitzGerald 1968), with very small values (Neckel 1966; Klare and Neckel 1967) and very large values (Sharov 1963) probably representing a true range, since the Gould belt exerts a strong influence in some directions. Similarly, the rate of increase of extinction in the galactic plane due to this matter is found to average 1–2 mag kpc^{-1} (Fernie 1962; Sharov 1963; Isserstedt and Schmidt–Kaler 1964; Neckel 1966; Scheffler 1967), although earlier work usually yielded 2–3 mag kpc^{-1}. It is interesting to note that, in order to achieve a uniform space density of stars around the Sun, Kapteyn (1904), following W. Struve and others, required a mean extinction rate of 1.6 mag kpc^{-1}. Recent values of the vertical extinction at infinity, derived from stars at high galactic latitudes, tend to be very close to zero (Feltz 1972). However, this may well be a reflection of the local "hole" in the interstellar material around the Sun and should not be construed as evidence against the validity of the cosecant law as an average law for the whole belt. Moreover, reddening near the galactic poles (as elsewhere) seems actually to be patchy rather than absent. Our present results, on the whole, agree well with other work, especially when it is noted that the stars in our solutions were selected according to distance, and so tend to give a somewhat higher extinction rate than the rate for stars selected according to apparent magnitude (compare Allen 1963).

It has sometimes been considered that dust along with neutral hydrogen (Davies 1960) is more prominent in the Gould belt than in the galactic belt. Some indirect evidence related to stellar magnitudes and radial velocities (Arshinova and Radzievskii 1971) has also suggested a greater mean extinction in the Gould belt, but our present data as well as the known concentrations of dark clouds (Lynds 1962) do not confirm this.

Some general features of our determinations of the extinction rate are worth noting. Within $\sim$100 pc of the Sun, the few available stars give confirming evidence of the "hole" in the dust distribution near the Sun (see Sec. VI). Beyond the "hole," the extinction rate climbs rapidly out to a distance of $\sim$300 pc, whereupon it begins to decrease slowly, probably because of an observational selection effect, namely, the higher detectability of the less obscured stars at a great distance from the Sun. In the Gould belt some of the decrease may be real since one passes beyond the highly obscured Sco-Oph domain into the somewhat less obscured Orion domain. A crude map of the projected distribution of interstellar dust, as determined from the stellar color excesses, shows some concentrations on the plane of the Gould belt just northward of the line of intersection with the galactic belt, and other concentrations in Sco-Oph, Per-Tau, and, more weakly, in Her-Lyr and Orion. In good agreement with this picture is the known distribution of dark clouds (Khavtassi 1960; Lynds 1962). Other authors (above) have already adequately treated the galactic belt.

VIII. CONCLUSION

The history of investigations into the local complex of O-B5 stars, luminous supergiants, clusters, and associations reveals that many questions have remained unanswered concerning the structure and composition of the two major belts into which the local complex is divided. In the present paper, we have demonstrated statistically the reality of the Gould belt as an entity separate from the galactic belt. Characteristic of each belt is a strong concentration of stars and dust to a flat sheet, with the Gould belt being about three times as compressed vertically as the galactic belt.

The galactic belt, out to a distance of approximately 1 kpc from the Sun, is inclined to the IAU galactic plane by $\sim 5°$. The Sun lies $\sim$24 pc above the mean plane of the belt. B stars are distributed more or less randomly on the mean plane, and the stellar population is heterogeneous in age.

The Gould belt has an inclination of $\sim 18°$ to the IAU plane, with the direction of tilt toward Orion. It extends as much as $\sim$800 pc in that direction and $\sim$300 pc toward Ophiuchus. The Sun lies effectively in the mean plane. The projected distribution of B stars resembles a "dragonfly," with five major features defining it. A crude "diameter" of the system is 750–1000 pc, with the formal center of star positions lying 150–250 pc toward Orion. Although the Gould belt stars do not have a unique age since star formation is apparently still going on, the main sequence in the H-R diagram for all the stars has a noticeable turnup at B2.5$\pm$0.5, corresponding to a nuclear age of 30$\pm$7 million years. However, the half of the Gould belt running from Ophiuchus to Taurus is older, spectroscopically, than the other half. There are about three times as many O-B2 stars per pc^2 in the Gould belt as in the galactic belt, but the respective areal densities of B3-B5 stars are nearly equal.

In the order of increasing concentration to the mean plane of each belt, one may place the stars, interstellar dust, and centers of star groups. The stars are about twice as dispersed vertically as are the group centers, which have characteristic heights of $\sim$15 and $\sim$45 pc in the Gould and galactic belts, respectively. The thickness of each belt is nearly uniform over the belt. The mean interstellar extinction seems to be about the same in both belts: 1.5 mag kpc^{-1}, although the obscuration is actually very patchy. No chemical composition differences are noticeable between the two belts. An eccentric "hole" of about 200 pc diameter occurs in the distribution of dust and O-B5 stars around the Sun; the O-B5 stars of the Gould belt may also tend to avoid the line of intersection of the two belts.

Further discussion of the various features of the two belts and the significance of the two-belt phenomenon as a whole will be taken up in a later paper. It may be possible, as other investigators have already attempted, to effect a cleaner separation of stars belonging to the Gould belt from those belonging to the galactic belt, by using kinematical data.

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APPENDIX: CATALOGS

Three catalogs of bright stars, young clusters, and associations are described here.

A. O-B5 Stars

A catalog of O-B5 stars has been prepared by searching the literature published up to the middle of 1966. Only fairly bright stars with U, B, V (or equivalent) photometry have been included. A limiting apparent magnitude of $V \approx 9$ characterizes the catalog, which contains 1265 stars. When available, MK classifications of the spectral type and luminosity class were adopted; the HD catalog provided most of the other spectral types, for which luminosity class V was assumed. A comparison of 693 stars with both HD and MK spectral types indicates that, on the average, an error of not more than one decimal subclass will be incurred by using the HD spectral type, in the range B0–B5. For a spectroscopic binary, the spectral type of the more luminous (or earlier) component was adopted, and the other component was ignored. When available, directly measured U, B, V mag were adopted; otherwise, published transformation equations converting other color systems to the U, B, V system were used. Correction of the visual apparent magnitude for duplicity was made only in the case where the two components had approximately equal spectral types; then the visual apparent magnitude was increased by 0.75 mag. The interstellar extinction correction was computed by forming the B-V color excess and evaluating $A_V = 3.0E_{B-V}$. Occasionally, a source did not list B-V but gave only E_{B-V}, which we adopted directly. Intrinsic B-V colors due to Johnson (1958) were accepted for O, Of, B, and supergiant Be stars, while, for giant and dwarf Be stars, Schmidt–Kaler's (1964) colors were accepted. Visual absolute magnitudes were taken from the following sources: Blaauw (1963) for O, B, and supergiant Be stars; Kopylov (1959) for Of stars; and Schmidt–Kaler (1964) for giant and dwarf Be stars.

The volume of completeness for the stars in our catalog depends critically on spectral type and luminosity class. For the stars of luminosity class V near the galactic plane, the limiting distance ranges from about 200 pc for B5 stars to about 800 pc for B0 stars. O stars and supergiants are probably very nearly complete out to 1 kpc. In making these estimates we have assumed that our catalog is complete down to apparent magnitude $V = 6$ and that the average interstellar extinction in the galactic plane is 2 mag kpc^{-1}. Star counts in successive cylindrical shells around the Sun confirm these completeness estimates, if we assume that the projected stellar distribution in the galactic plane is uniform. Thus, within 800 pc of the Sun, our catalog for all the O-B5 stars is probably about one-third complete.

B. Luminous Supergiants

The catalog of supergiants prepared by Humphreys (1970) has been adopted. However, we have excluded A, F, G, and K supergiants of luminosity class Ib. These latter objects are descended from main-sequence stars with spectral types ranging from B3 to G2, and so do not belong primarily to the population group studied in this paper. Humphreys's data and methods of reduction are entirely compatible with ours, except that she adopted Johnson's (1966) intrinsic colors, which, for supergiants, are very slightly more negative than his 1958 colors. About 60% of the supergiants within 800 pc of the Sun have spectral types in the range O-B5, while about 20% have spectral types M; not all of them belong to known clusters or associations.

C. Young Clusters and Associations

A revised catalog of clusters and associations has been prepared by Becker and Fenkart (1971). We have selected only those objects which lie within 800 pc of the Sun and whose main sequences in the H-R diagram turn up at spectral type B5 or earlier. The turnups have been determined by recourse to the original published H-R diagrams. To the Becker–Fenkart list, we have added the δ Lyr moving group (Eggen 1968), the Vel A association (Brandt *et al.* 1971; Upton 1971; Straka 1973), and the Sct OB2 and Cyg OB7 associations (Schmidt 1958; Ruprecht 1966). The Pleiades moving group contains several clusters having possible members with spectral types earlier than B6 (Eggen

TABLE A-I. List of clusters and associations within $\rho=800$ pc that have a spectral type of the main-sequence turnup at B5 or earlier.

Group	l	b	r(pc)	Sp	Belt
M25	13°6	− 4°5	600	B5:	Galactic
Sct OB2	23.0	− 1.0	730	<B0.5	Galactic
IC 4665	30.6	+17.1	330	<B4	Gould
δ Lyr	66.8	+15.5	320	<B5	Gould
Cyg OB7	90.0	+ 2.0	740	B0.5:	Galactic
Lac OB1	97.0	−17.0	600	B1.5:	Galactic
Tr 37 (Cep OB2)	99.3	+ 3.7	705	<B0	Galactic?
NGC 7160 (Cep OB2)	104.0	+ 6.5	700	B1:	Galactic?
Cep OB3	110.3	+ 2.8	725	B0:	Galactic?
α Per (Per OB3)	147.0	− 6.0	170	B3	Gould
Per OB2	160.0	−16.0	400	B1	Gould
NGC 2264 (Mon OB1)	202.9	+ 2.2	715	O7	Galactic
Ori OB1	206.7	−20.7	415	O9	Gould
Cr 121 association	235.4	−10.4	760	B0.5:	Galactic?
Vel A	265.0	− 5.0	500	O7	Gould?
IC 2391	270.4	− 6.9	153	≤B3	Gould?
IC 2602	289.6	− 4.9	145	<B0	Gould?
Sco OB2	352.0	+20.0	160	B0.5	Gould
NGC 6475	355.9	− 4.5	230	B5::	Galactic

1965), but the membership of most of these stars is too doubtful (Eggen 1967) for our use of the clusters in question. Table A-I contains a list of the clusters and associations used, together with the following data for each: new galactic coordinates; distance from the Sun; spectral type of the main-sequence turnup; and belt membership.

R associations have been cataloged by Racine (1968), van den Bergh (1968), and Racine and van den Bergh (1970). About half of them are embedded in or are coterminous with standard clusters and associations in the Becker–Fenkart list. A similar affiliation is shown by the T associations, cataloged by Kholopov (1959) and Wenzel (1961). Therefore, we shall not consider these associations separately.

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